Collisions of Uranium at RHIC

- Discoveries with collisions of gold at RHIC
- Why are uranium beams useful for RHIC science?
- EBIS: the brand new beam source for RHIC

BROOKHAVEN NATIONAL LABORATORY

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Community Advisory Council
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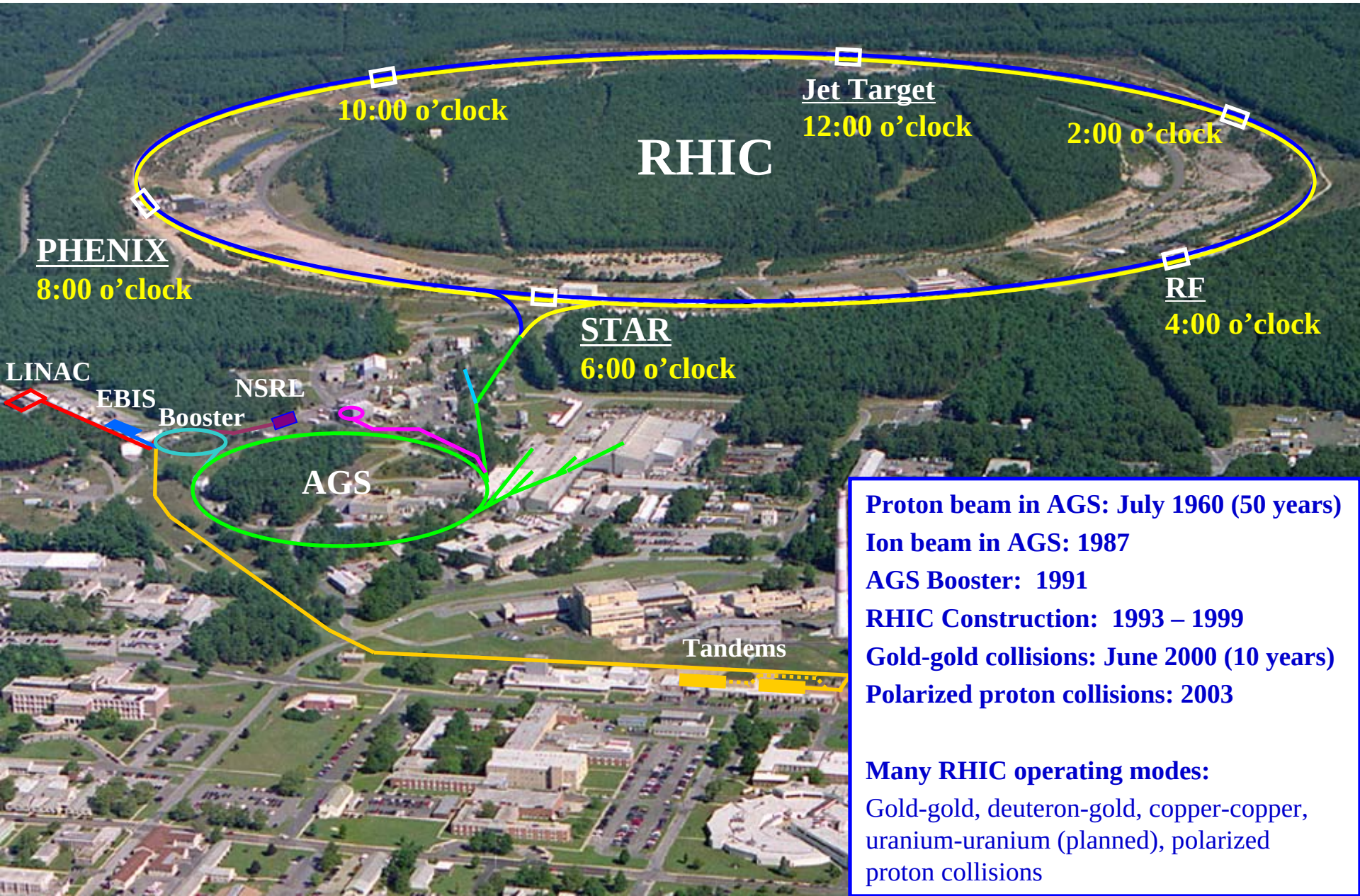
RHIC – a High Luminosity (Polarized) Hadron Collider



Proton beam in AGS: July 1960 (50 years)

Ion beam in AGS: 1987

AGS Booster: 1991

RHIC Construction: 1993 – 1999

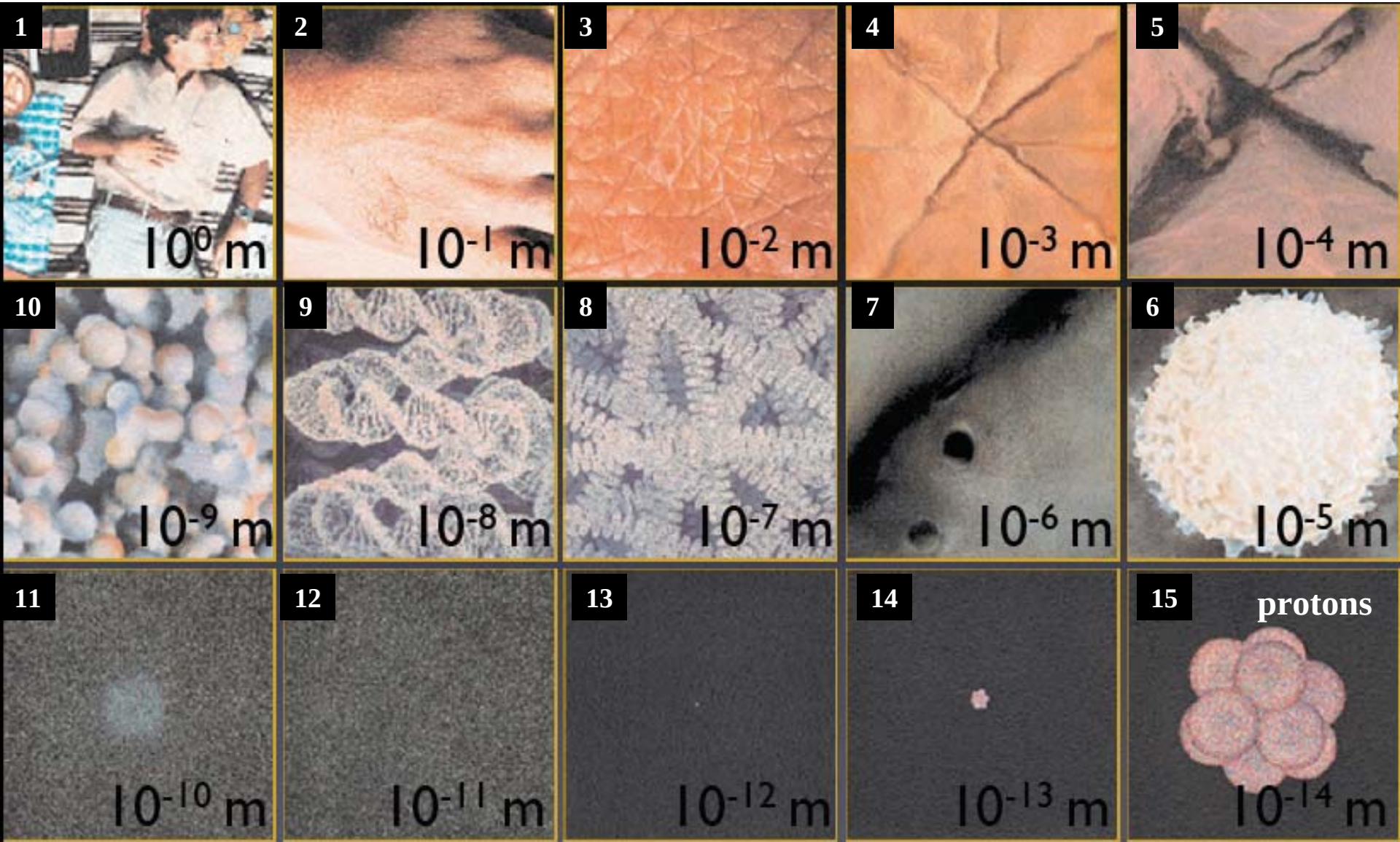
Gold-gold collisions: June 2000 (10 years)

Polarized proton collisions: 2003

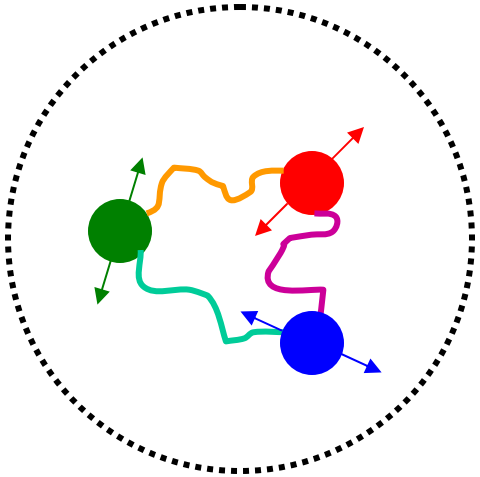
Many RHIC operating modes:

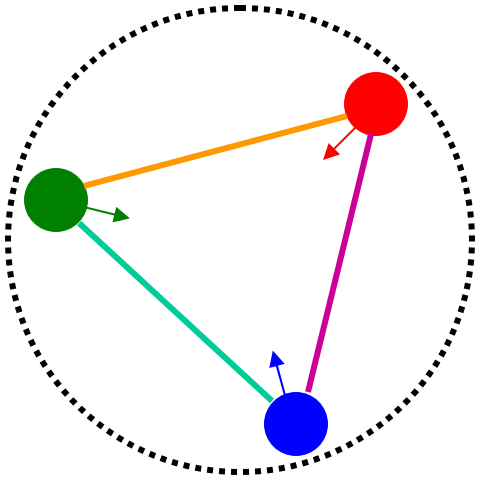
Gold-gold, deuteron-gold, copper-copper, uranium-uranium (planned), polarized proton collisions

From us to the proton:
the last picture is 100,000,000,000,000 x magnified



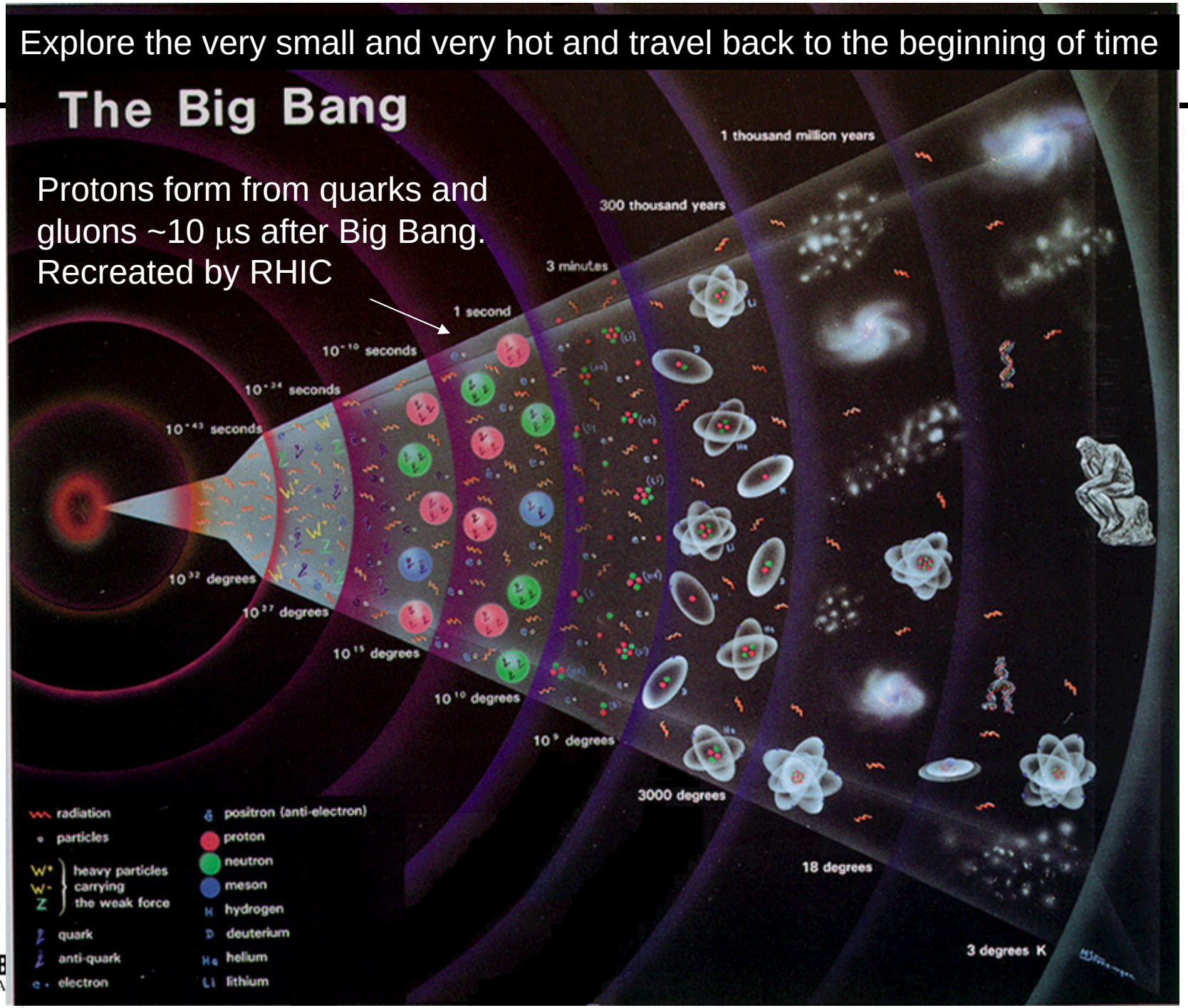
The Strong Force





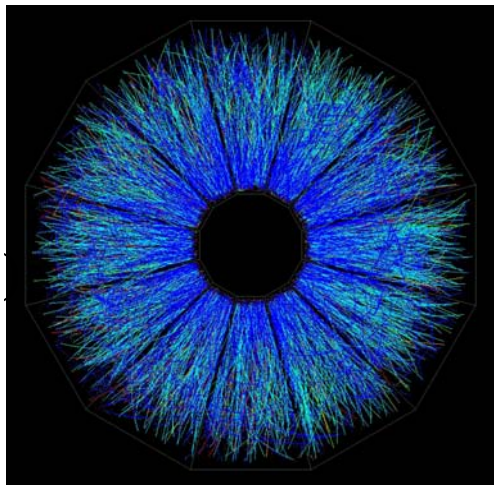
- The strong force holds 3 quarks together to form the proton (and also the neutron)
- It acts like a string (called gluon): either loose or tight
- When string is loose quarks move at 99.99% of speed of light
- High energy of quarks and gluons inside the proton comes from Big Bang. It gives us our mass ($E = mc^2$)
- During collisions at RHIC the quarks are liberated from the proton – the strings break.
- A new state of matter is formed: the Quark-Gluon-Plasma. It last existed micro-seconds after the Big Bang.
- Discovery at RHIC: the Quark-Gluon Plasma (and the early universe) behaves like a perfect liquid

Explore the very small and very hot and travel back to the beginning of time



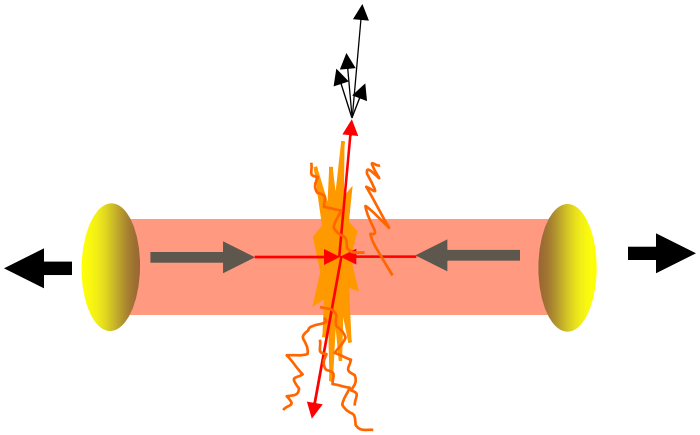
Mini-Bang at RHIC: Matter at Extreme Temperature and Density

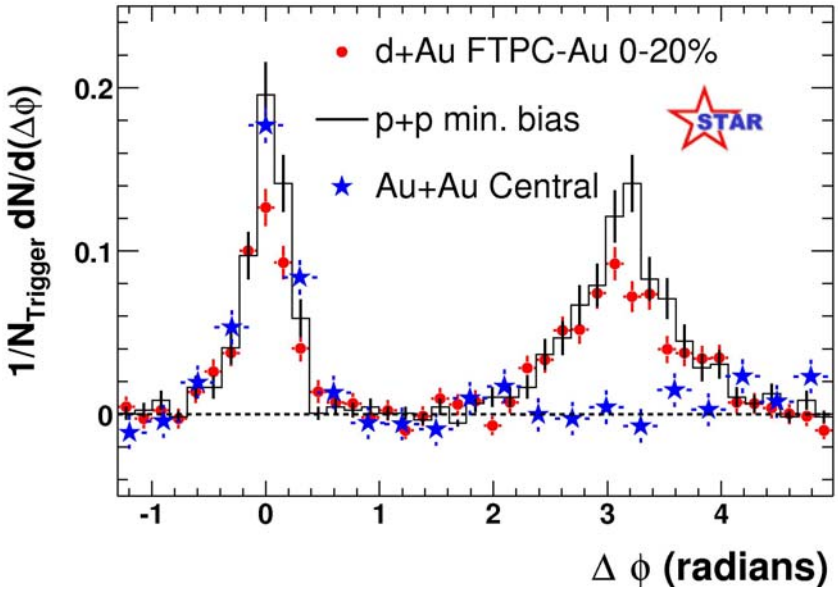
- Colliding gold at 100 + 100 GeV/nucleon:
  Produce and explore a new state of matter
  - Formation phase: scattering of quarks/gluons in gold
  - Hot and dense phase: new state of matter
  - Freeze-out phase: emission of particles into detector
  - Discovered a new state of matter ("quark-gluon plasma")
  - Last existed microseconds after Big Bang
  - Extremely dense and strongly interacting
    - Matter with strong, self-interacting force
  - Hottest matter in the universe:
    250,000 times hotter than the center of the sun
  - Behaves like a perfect liquid (not like a gas)
  - Produced exotic anti-matter
    for a very brief moment
  - Possibly produced bubbles of matter
    with broken mirror symmetry

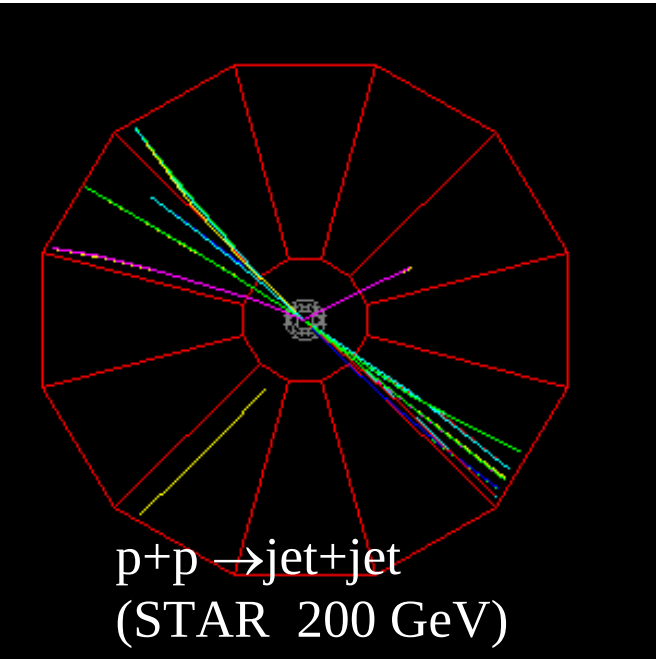


Animation by Jeffery Mitchell (BNL).
Simulation by the UrQMD Collaboration

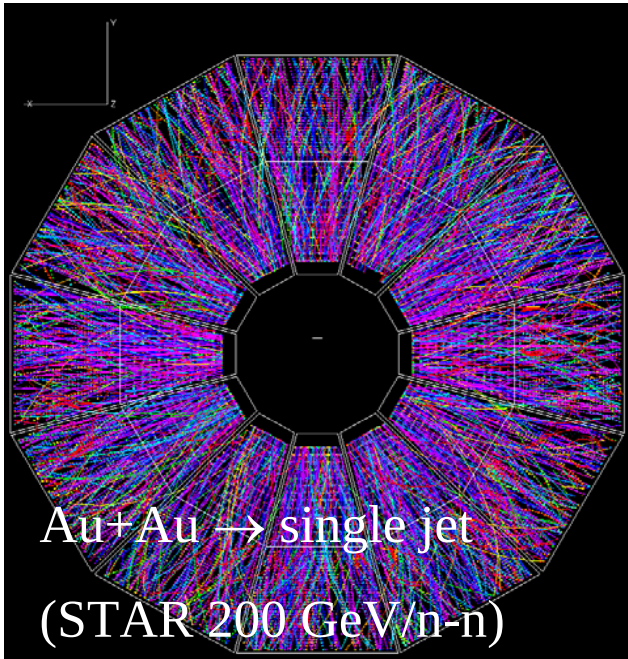
Hard Scattering at RHIC







p+p →jet+jet
(STAR 200 GeV)

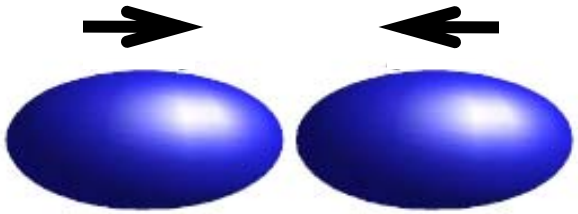


Au+Au → single jet
(STAR 200 GeV/n-n)

Why are Uranium Beams Useful for RHIC Science?

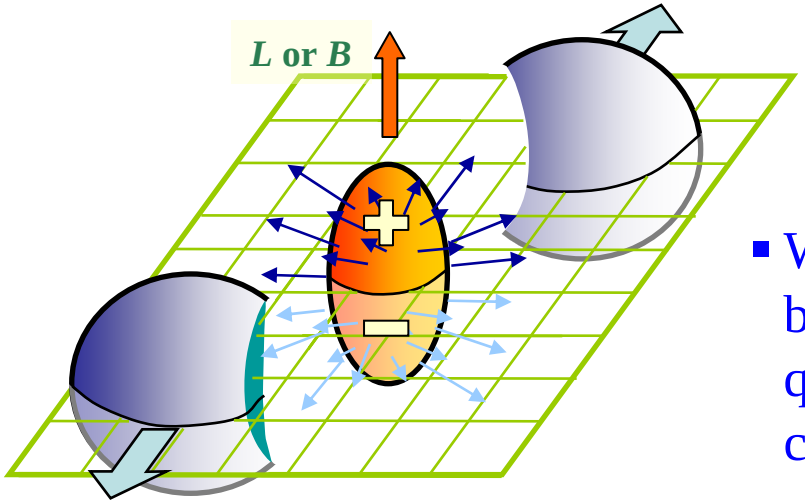
- Uranium is the most highly deformed heavy nucleus available for use in beams:
  - the naturally occurring isotope U-238 is football-shaped, with a length ~ 30% larger than its diameter, and is quite distinct from the nearly spherical nucleus of gold

- The deformation can be exploited to produce quark-gluon plasma under even more extreme conditions than studied with gold-gold collisions:

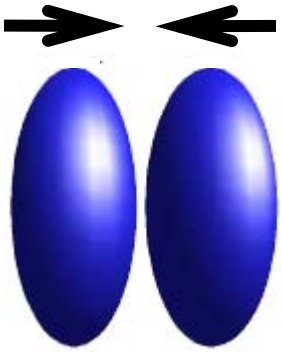


  - "tip-tip" collisions produce much higher energy density of matter than the most energetic gold-gold collisions yet studied at RHIC
  - Is the matter still a perfect liquid or will it start to behave like a gas?
  - Important test of our understanding of this new state of matter

Study of the Bubbles of Broken Mirror Symmetry



- non-head-on collisions of gold produce an ultra-strong magnetic field, stronger than any known in the present universe!
- With this extreme magnetic field, bubbles of broken mirror symmetry can form inside the quark-gluon plasma, observed in RHIC as charge asymmetry.
- Analogous to the formation of bubbles of broken matter-antimatter symmetry created in the very early universe that could explain the lack of antimatter today so important to our existence!



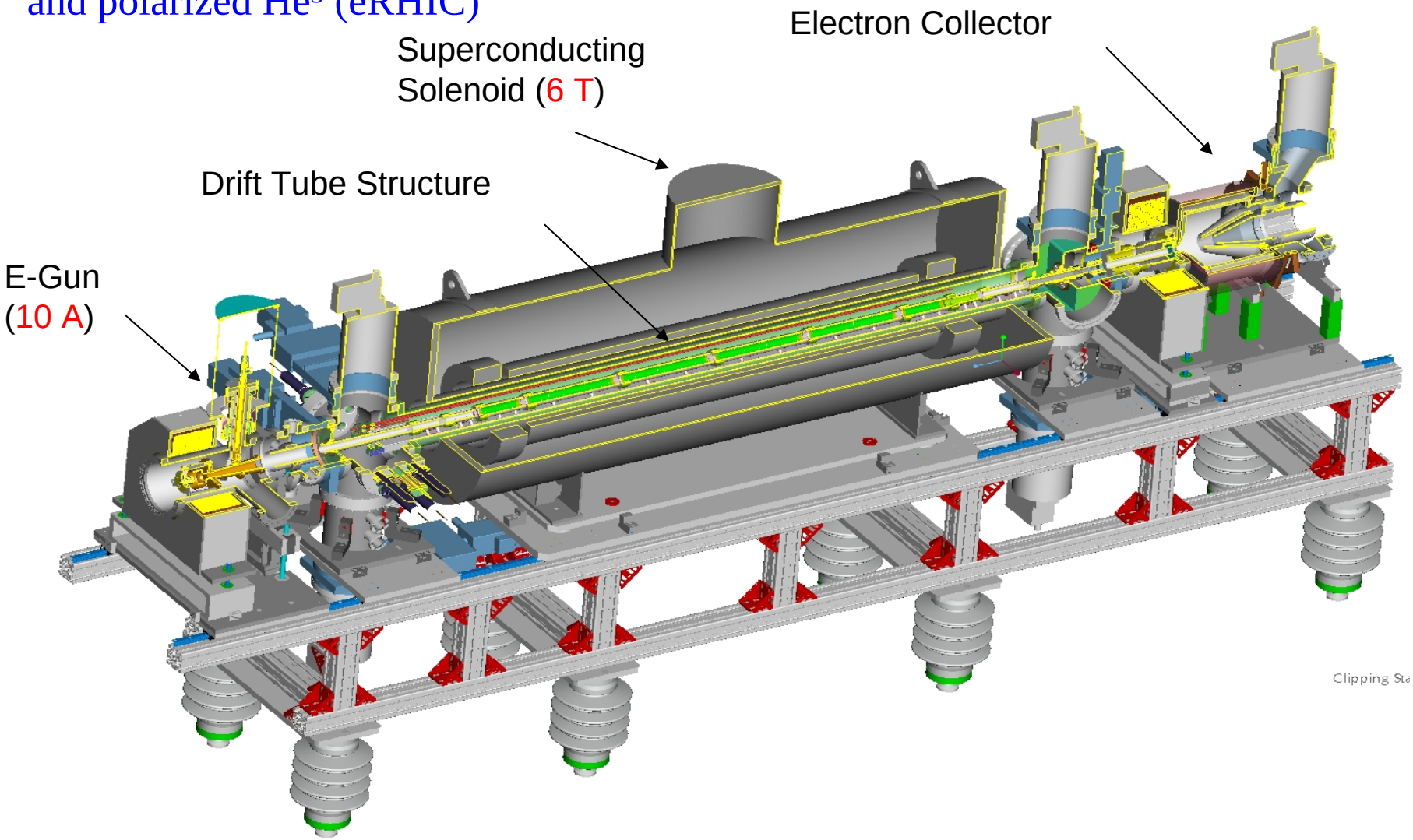
- head-on "body-body" collisions of uranium produce a strongly deformed quark-gluon plasma without a magnetic field, and should NOT produce bubbles of broken mirror symmetry.

Uranium Beams

- Gold ion collisions at RHIC have used less gold than is found in a single wedding ring over RHIC's ten years of operations,
- Amount of uranium used will be extremely small and not pose any radiation or any other risk to either Brookhaven Lab staff or the public.
- A handful of soil typically has more naturally occurring uranium than we'll be using in a year at RHIC.
- RHIC will use the dominant naturally occurring form of uranium, U-238 (uranium with 238 protons and neutrons), which cannot "split" and sustain a nuclear chain reaction like U-235, the fuel used in nuclear reactors.

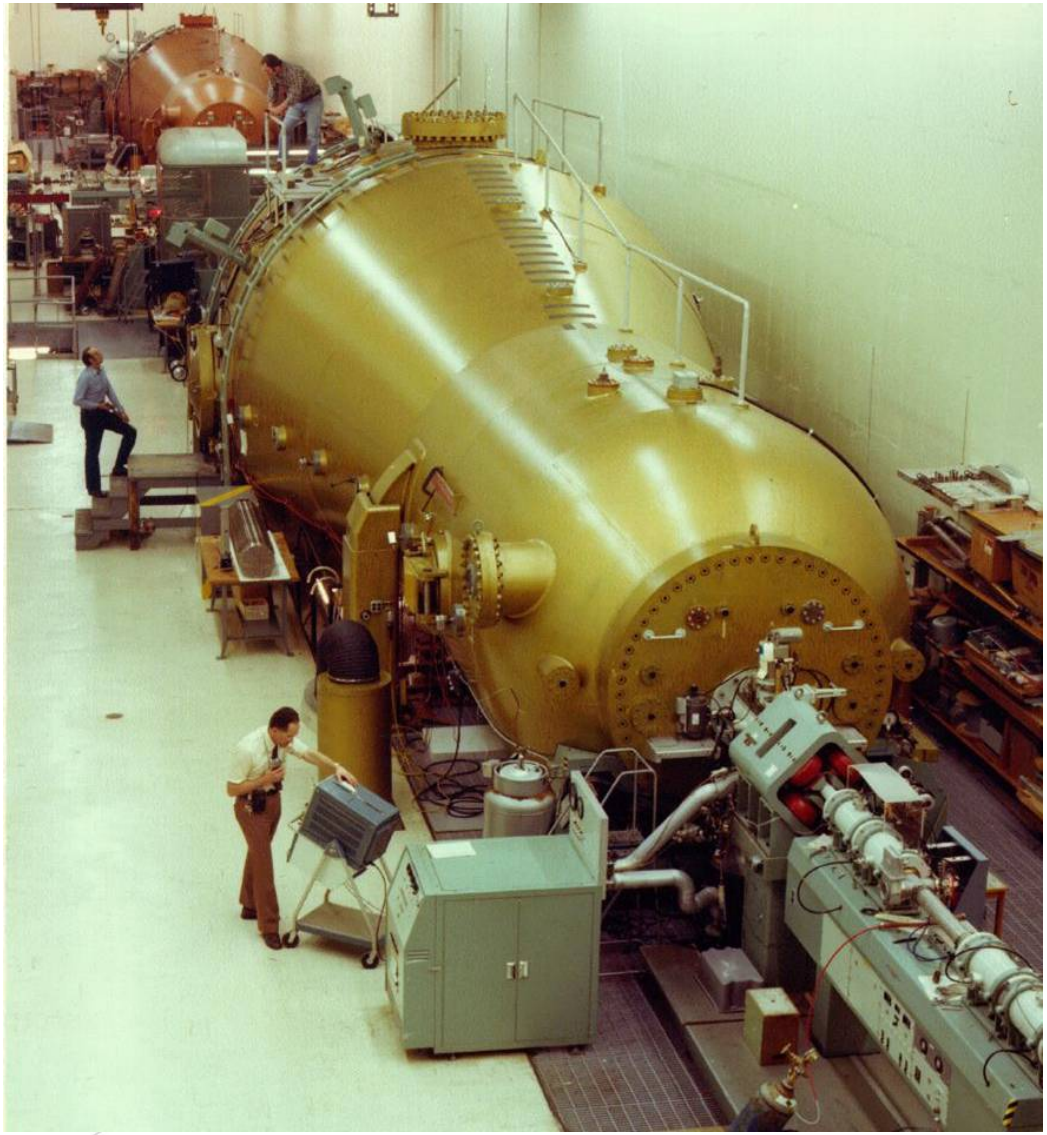
Electron Beam Ion Source (EBIS)

- New high brightness, high charge-state pulsed ion source, ideal as source for RHIC
- Produces beams of all ion species including noble gas ions (NSRL), uranium (RHIC) and polarized He^3 (eRHIC)

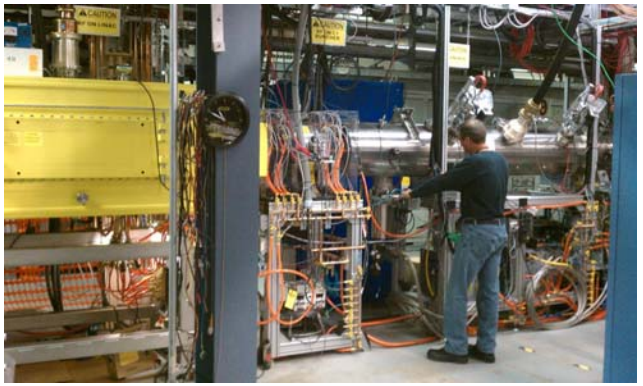


EBIS - A Very Compact New Accelerator

Tandems



EBIS



Summary

- The structure of our world today was formed during the first moments of the live of our universe
- After the discovery of the quark-gluon plasma, present only at the birth of the universe, RHIC is now exploring the novel and exotic properties of this matter in great detail and with new probes.